Improvement in Aided Sound Localization with Open Earmolds: Observations in People with High-Frequency Hearing Loss

William Noble*
Shaune Sinclair*
Denis Byrne†

Abstract

Sound localization ability was tested in nine people with marked, bilateral, high-frequency hearing loss and little or no low-frequency loss. They had previously been fitted bilaterally with behind-the-ear hearing aids and closed earmolds and showed poorer aided than unaided localization performance. Further testing was conducted in unaided and aided conditions, with the aids coupled to closed, open, and "sleeve" (extra-open) earmolds. Closed earmolds affected localization, particularly in the frontal horizontal plane, but performance was restored to unaided levels in both of the open earmold conditions. In the lateral vertical plane, localization was found to correlate with the extent of difference between low- and high-frequency hearing levels. That result is discussed in terms of a dynamic, low-frequency localization cue. Open earmolds are argued to improve aided sound localization for the present sample by permitting undistorted access to low-frequency interaural time/phase differences.

Key Words: High-frequency hearing loss, open earmold, sound localization

Abbreviations: BTE = behind-the-ear (hearing aids), FHP = frontal horizontal plane, HTL = hearing threshold level, ITD = interaural time difference, LHP = lateral horizontal plane, LVP = lateral vertical plane, NAL = National Acoustic Laboratories

In this paper, we describe an experiment that involved fitting open earmolds to hearing aid clients with bilateral, high-frequency hearing loss and observing the effects on their sound localization ability. Open earmolds have been used in cases of unilateral hearing loss, in which a signal is routed from the side of the impaired ear to the nonimpaired side, so as to provide, along with the unamplified input to the nonimpaired ear, a semblance of interaural differences and, hence, supposedly improved directional hearing (Briskey, 1978). Bilateral open earmold fittings are associated with improved speech intelligibility (Cox and Alexander, 1983) and also offer better sound quality of the wearer's own voice, due to release from the "occlusion effect" (Macrae, 1983), an outcome that is also achieved by venting of the more commonly used closed type of earmold.

Sound localization is negatively affected by most forms of hearing loss (Jongkees and Van Der Veer, 1957; Häusler et al, 1983; Noble et al, 1994), and hearing aids can add further to the disturbance of this function (Noble and Byrne, 1990; Byrne et al, 1992). One reason is that parts of the aid physically occupy the region of the outer ear—the concha—which has a critical role in localization. In addition, hearing aids typically provide little amplification at frequencies higher than 4 kHz. These two features mean that transformations of the input signal at the pinnae are no longer available. Such transformations require both an unobstructed outer ear and a range of sound energy at frequencies around 4 kHz and higher. Pinna-related transforms have been shown to be directionally dependent (Shaw, 1982) and to offer significant cues for vertical plane localization, as well as aspects of localization in the horizontal plane (Musicant and Butler, 1984; Butler et al, 1990).
Recently, we investigated the use of open earmolds for people with bilateral, low-frequency hearing loss, but only slight loss at higher frequencies (Byrne et al, in press). We found that such listeners can benefit in terms of localization in the vertical plane and in the lateral horizontal plane (LHP). There were decrements in localization using standard closed earmold hearing aids, compared with unaided listening. Some recovery was observed using a standard open earmold: additional benefit was obtained using a special “sleeve” earmold. The sleeve earmold offers virtually no interference with the earmold sound field, and, in the sample in question, it served to restore localization performance to levels approaching those unaided.

A less obvious application of an open earmold, in terms of localization, is among people with bilateral, high-frequency hearing loss and relatively slight low-frequency loss. The particular region that may show improvement is the frontal horizontal plane (FHP) (i.e., where sounds are displaced horizontally to the left and right of the body’s midline). We have observed (Noble and Byrne, 1990; Byrne et al, 1992) that some people with sensorineural hearing loss, fitted with two behind-the-ear (BTE) hearing aids and a standard type of earmold, show poorer FHP localization aided than unaided. This may be due to distortions of interaural, low-frequency time/phase differences, arising from inconsistencies in the aided/unaided components of the input signal. Wightman and Kistler (1992) showed that low-frequency interaural time (IT)/phase difference cues predominate over high-frequency interaural level cues in FHP localization in the case of normal hearing. Time/phase differences, for human listeners, offer localization cues for signals below about 1.5 kHz, whereas level cues are more noticeable at high frequencies (Mills, 1972). People with bilateral hearing loss characterized by poor high-frequency hearing and mild or slight low-frequency loss may rely more on time/phase cues. Hence, they may be likelier to have better unaided than aided frontal horizontal localization because time/phase cues are less distorted in unaided conditions. Thus, open earmolds in these cases, plus amplification only at higher frequencies, could provide similar localization to that observed in unaided listening.

It is not obvious if other advantages for localization will accrue to people with good low but poor high-frequency hearing loss using open earmolds. In lateral regions, sources displaced from the interaural axis cannot be distinguished on the basis of low-frequency IT/phase cues alone. The “cone-of-confusion” effect (Woodworth and Schlosberg, 1954; Blauert, 1969/70) means that a source at, say, X° in front of the interaural axis may be heard as though at a position X’ above, behind, or below it. A possible counter to this ambiguity is a low-frequency spectral notch, generated by the shoulders and torso, at around 1 kHz (Kuhn and Guernsey, 1983). This may allow the locations of at least front from rear lateral sources to be distinguished (Weinrich, 1982).

If an open earmold permitted this notch to be heard undistorted, it might affect LHP performance. Lateral vertical localization is typically a little better than frontal vertical (Butler et al, 1990; Noble el al, 1994). This is due to the combination of pinna transformations and time/phase differences in the lateral vertical plane (LVP), as against involvement of the pinnae alone in the frontal vertical plane. If an open earmold permits less distorted access to time/phase cues, then, together with any remnants of a pinna cue, this might benefit lateral vertical localization.

In summary, the aim of the present study was to observe the effect of open earmolds on sound localization ability in people with marked high-frequency hearing loss and slight or no loss at low frequencies. The primary expectation was that open earmolds should benefit FHP performance in such listeners. A more exploratory feature of the study concerned effects on lateral horizontal and vertical plane performance.

**METHOD**

**Participants**

Recent records of an Australian Hearing Services clinic were scrutinized to identify people with bilateral sensorineural hearing loss who had been fitted with bilateral BTE hearing aids and who showed severe high-frequency hearing losses combined with nearly normal hearing at lower frequencies. The selection criteria were (1) average better ear hearing threshold level (HTL) at 0.25 and 0.5 kHz of 20 dB or less and (2) four-frequency average better ear HTL (0.5–4 kHz) ≥30 dB (“better ear” defined as the ear with lower HTL at any tested frequency). People meeting these criteria, according to the clinic records, were tested to compare unaided localization ability with localization when listening with their own hearing aids. Those exhibiting poorer aided than unaided
localization, in terms of absolute accuracy in either the FHP or LHP, were invited to participate in the main experiment. Eighteen people completed the initial test session, of whom nine showed poorer aided performance. There were eight males and one female in this sample, whose average age was 69.1 years (SD = 4.1).

A hearing threshold test carried out toward the end of the main study revealed, in three cases, a variation from the clinic records, such that the 20-dB criterion at 0.25 to 0.5 kHz was exceeded (all but two participants had bilaterally symmetrical hearing losses, defined as an interaural difference in four-frequency average hearing level of less than 15 dB). The main experimental outcomes of interest were not affected by inclusion or exclusion of the three people exceeding the 20-dB criterion and, indeed, retaining them helped to illuminate a further feature of the results. Thus, data for all nine people are used in the analyses reported below. The average better ear hearing threshold levels (HTLs) of the sample are shown in Figure 1.

Procedure

To test localization function, signals were presented from any of 11 numbered loudspeakers in the FHP, five on either side of a center loudspeaker. In the lateral orientation, the test arrangement consisted of these 11 plus nine further loudspeakers arrayed vertically—five above and four below the center loudspeaker, which was thus common to both lateral horizontal and vertical planes (see Byrne et al [1992] for diagram). For data analysis purposes, responses to the center loudspeaker were assigned to the vertical plane score in lateral position tests. The loudspeakers were arrayed at 18° intervals in hemicycumbences of 1.22-m radius. The numbered loudspeaker positions were visible to the listener, all testing being carried out under normal lighting conditions in a medium-sized anechoic chamber.

In the frontal orientation, listeners aligned their interaural axis with the leftmost and rightmost of the horizontal plane sources; in the lateral orientation, the interaural axis was aligned with the center loudspeaker common to both planes. The signal was recorded pulsed pink noise, each pulse 150 msec, with 10-msec rise and fall times, and 50-msec interpulse intervals. Total signal duration was 0.9 seconds, accommodating at least four complete pulses per trial. There were two fixed presentation levels—65 dB SPL and 50 dB SPL—with random variation by 0 dB or ±3 dB on any trial.

Testing was conducted over four separate sessions. An initial session involved practice trials on bilaterally aided (own system) and unaided conditions, in frontal and lateral orientations, with the signal at 65 dB SPL and 50 dB SPL and the aids set throughout at each listener's preferred level for conversational speech. The practice trials were followed by formal tests using blocks of trials in the above conditions. Upon determining whether performance, in terms of absolute accuracy, was better unaided than aided, an invitation was given to take part in the main experiment. The nine people so identified, and agreeing to further participation, had ear impressions taken and were asked to return for experimental fittings and further localization testing on three subsequent occasions.

In the next three test sessions, listeners were tested unaided and also when fitted bilaterally with three experimental earmolds. The first were their own earmolds, temporarily modified to close any vents in the mold (the earmolds used by eight of the nine participants had 1- or 2-mm parallel vents). The second were "open" earmolds—a modified form of the "G-mold"—half-ring-shaped structures extending from the intratragal notch, around the back of the concha, and into the cymba concha. The portion adjacent to the ear canal sits 2 to 3 mm out from the entrance, holding the tubing that extends 8 to 10 mm into the ear canal, and the lower part fills the intratragal notch obscuring the lower part of the ear canal entrance. The third were the "sleeve" earmolds, thin plastic rings, about 4 mm long, and fitting snugly into the outer end of the ear canal. These provided firm anchors to hold the sound delivery tubes, which were glued to the inside of the plastic
sleeves. The tubes extended 8 to 10 mm into each ear canal, leaving the ear canal otherwise completely open. The three types of earmold are shown in Figure 2.

In all test sessions, the listeners' own hearing aids were coupled to the experimental earmolds, with the volume, in open earmold conditions, at the preferred level or reduced to a level that overcame acoustic feedback. Those volume settings were then used in the other aided conditions. Figure 3 shows the group average insertion gains for the three types of earmold fittings, as well as the group average better-ear National Acoustic Laboratories' (NAL) prescription (Byrne and Dillon, 1986). The open and sleeve earmold fittings show a reduction in insertion gain at the low frequencies when compared to the closed earmold fitting. This is because the open and sleeve earmolds allow low-frequency sound to "escape" and dissipate outside the ear, a well-known effect of venting in earmolds (Dillon, 1991). Also shown is the group average insertion gain for the closed earmold fitting for the initial screening visit. The closed earmold insertion gain for that visit was on average larger than the closed earmold insertion gain for the main study. This is because several listeners needed a reduction in gain to avoid feedback when using the open and sleeve earmolds.

Localization testing was carried out in unaided conditions, and in aided listening with closed earmolds, open earmolds, and sleeve earmolds, at 65 and 50 dB SPL, for FH, LH, and LV planes. Test orders were counterbalanced across listeners and test occasions. In a test session, for each condition, there were 11 trials for sources in the FHP and 20 trials for the combined LH and LV planes. Each loudspeaker was activated once, in random order, with the same regime of testing repeated on two subsequent visits. Each test session lasted between 1 and 1.5 hours. In the third test session, a pure-tone hearing threshold test was also conducted. In localization tests, listeners began each trial facing the central loudspeaker (FHP testing), or facing the leftmost one (LHP/LVP testing). Head movements were permitted during signal presentation, and the task was to identify, by number, the loudspeaker judged to be where the sound had come from. No training or feedback was given.

RESULTS

Initial Unaided/Aided Difference

As an indication of the nature of the difference between those showing poorer aided than unaided performance in the initial test, versus those showing no difference (or better aided), the mean absolute accuracy scores, in FH and LH planes, aided versus unaided, for the 65 dB SPL signal, are given in Table 1. The distinction in performance is in the aided condition, there being no difference between the two groups in unaided performance. Thus, the effect, where it occurs, is due to the hearing aids and is not contributed to by poorer intrinsic localization function. For the nine people forming the sample in the main experiment, there was a slight but statistically nonsignificant improvement in both unaided and "closed" aided performance in the main experiment compared to the initial unaided and "own aided" results shown in Table 1. This outcome is similar to one observed in a previous reliability study (Lepage et al, 1991). The result shows that the "closed" condition in the main experiment was no more detrimental to aided performance than the initial "own aided" condition.
Table 1  Average Number Correct (of 33 Maximum in FHP; 30 Maximum in LHP) in Aided and Unaided Listening for the Signal at 65 dB SPL, among Those Showing Poorer Initial Aided than Unaided Performance versus Those Showing No Difference or Better Aided

<table>
<thead>
<tr>
<th></th>
<th>FHP (SD)</th>
<th>LHP (SD)</th>
<th>FHP (SD)</th>
<th>LHP (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poorer Aided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aided</td>
<td>18.7 (4.7)</td>
<td>15.8 (6.2)</td>
<td>28.7 (5)</td>
<td>23.5 (4.1)</td>
</tr>
<tr>
<td>Unaided</td>
<td>28.3 (5.6)</td>
<td>20.8 (5.7)</td>
<td>27.8 (4.5)</td>
<td>22.0 (4.5)</td>
</tr>
<tr>
<td>No Difference or Better Aided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Main Experiment Effects: Frontal and Lateral Horizontal Planes

Absolute Accuracy

Figure 4 shows the absolute accuracy of horizontal plane performance across the four listening conditions (all test session results combined) for the two signal levels. One-way ANOVA showed a significant effect (p < .001) for earmold condition in the FHP for the 65 dB SPL signal. Post hoc testing (Tukey's HSD) showed that the mean differences in the number of correct responses between each of the three “open” conditions (unaided, open, sleeve) and the closed condition all exceeded the p = .01 critical value of 4.9. None of the “open” conditions differed from each other. The same trend was observable for the 65 and 50 dB signals in the LHP, without achieving significance overall. It was observed that, in the FHP, the 50-dB signal was inaudible on some trials for some listeners in the unaided condition (i.e., the listener did not respond to some presentations). This has the effect of decreasing the absolute accuracy score and, consequently, increasing the error term in the ANOVA (reflected in the large standard deviation in that particular condition—top right panel of Fig. 4). The analysis was repeated using only the three aided conditions, and this showed a significant overall effect (p = .03); post hoc testing indicated that the difference in correct responses between closed and sleeve earmold conditions exceeded the p = .05 critical value of 5.4.

Error Magnitude

Analyses of the magnitude of HP errors showed no significant effects of consistent trends across listening conditions. In the FHP, average error magnitudes were about 1-to-1.5 loudspeakers (18–27°), and in the LHP they were about 3-to-3.5 loudspeakers (54–63°). The greater error magnitude in the lateral region is due to the occurrence of front-back and cross-plane errors.
Table 2  Averages of the Total Number of Front/Rear and Rear/Front Errors in the Lateral Horizontal Plane across Unaided and Various Aided Conditions for the Signal at 65 and 50 dB SPL

<table>
<thead>
<tr>
<th>Signal Level</th>
<th>Unaided (SD)</th>
<th>Closed (SD)</th>
<th>Open (SD)</th>
<th>Sleeve (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 dB SPL</td>
<td>0.9 (1.2)</td>
<td>1.3 (1.8)</td>
<td>0.8 (1.4)</td>
<td>1.2 (1.3)</td>
</tr>
<tr>
<td>50 dB SPL</td>
<td>1.0 (1.1)</td>
<td>3.2 (3.4)</td>
<td>1.2 (1.7)</td>
<td>1.6 (1.7)</td>
</tr>
</tbody>
</table>

**Front-Back Errors**

In the LHP, the averages of total numbers of errors from rearward to forward of the interaural axis, and vice versa (back-to-front and front-to-back errors), across conditions, are shown in Table 2. For the 65 dB SPL signal, it may be seen that there are very few such errors (maximum possible is 30), and there is no significant variation across conditions. For the 50 dB SPL signal, such errors are noticeably higher in the closed condition: across earmold conditions, $F = 2.29, p = .1$.

**Lateral Vertical Plane**

The absolute accuracy in LVP performance is shown in Table 3. With 10 positions, each tested three times, a chance performance level is about 3. Clearly (and expectedly), LVP performance is very inaccurate, but it is better than chance for open earmold conditions, particularly at the higher signal level. There was no statistically significant effect for earmold condition with the 65 dB SPL signal. For the 50-dB signal, the differences across conditions yielded $F = 2.4, p = .09$.

A count was made of the number of cone-of-confusion errors arising from sources in the LVP. Aside from front/back errors, cone-of-confusion errors are almost exclusively due to attributions across vertical plane quadrants (above to below the interaural axis and vice versa) or from the vertical to the horizontal plane (Noble et al, 1994). Both exact and "fuzzy" cone-of-confusion errors were counted, where a fuzzy error is an attribution to a position adjacent to (in this case, ±18° of) the exact cone-of-confusion position. This procedure is justified by the fact of inexact mappings for individual listeners between the formal and actual geometry of auditory space (Wightman and Kistler, 1993). The numbers of cone-of-confusion errors are shown in Table 4. There is an evident increase in the incidence of vertical plane cone-of-confusion errors in closed conditions: for the 65 dB SPL signal, $F = 2.79, p = .06$; for the 50 dB signal, $F = 2.89, p = .05$.

**Correlations with Hearing Threshold Level**

To consider which features of hearing level relate to different components of performance, we examined the correlations between HP and VP accuracy in unaided conditions and better-ear thresholds at individual frequencies. The number of correct responses in the FHP, for both the 65-dB and 50-dB signals, was significantly (negatively) linked with HTL at lower frequencies (0.25 and 0.5 kHz, correlations ranging from $-0.74$ to $-0.9$). The higher the HTL, the lower the absolute localization accuracy. A similar correlation pattern was observed for the 50 dB SPL signal in the LHP. There was no clear indication that hearing level around 1 kHz was related to LHP accuracy in unaided listing or, specifically, to the rate of front/rear and rear/front errors (this relates to the possible role of a notch in that frequency region). For the 65-dB signal,
Table 4  Cone-of-Confusion Errors for Lateral Vertical Plane Sources

<table>
<thead>
<tr>
<th>Signal Level</th>
<th>Unaided (SD)</th>
<th>Closed (SD)</th>
<th>Open (SD)</th>
<th>Sleeve (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 dB SPL</td>
<td>7.6 (5.0)</td>
<td>10.2 (5.4)</td>
<td>9.1 (4.2)</td>
<td>7.8 (4.7)</td>
</tr>
<tr>
<td>50 dB SPL</td>
<td>8.9 (5.8)</td>
<td>13.0 (4.8)</td>
<td>10.8 (3.7)</td>
<td>10.6 (3.4)</td>
</tr>
</tbody>
</table>

the highest correlation with accuracy, unaided, in the LHP, was with HTL at 1 kHz, but this was only -.35 (ns).

No notable links were observed, in general, between front/rear errors and HTL, although correlation analysis of such errors and HTL is limited by the fact that front/rear errors were infrequent in the present experiment, thus restricting the range of values for analysis. The exception was in the closed aided condition with the signal at 50 dB SPL (see Table 2). In that condition, we observed a very strong positive relation between number of front/rear errors and average HTL across 0.25 to 1 kHz (r = .84): the higher the HTL, the greater the number of front/rear errors. There were no other notable correlations with HTL in that earmold/signal condition.

The analysis of LVP unaided performance against HTL at individual frequencies revealed consistently, often significantly, negative correlations at 0.25 to 1 kHz. But a clear reversal of this relation was observed for frequencies higher—at each frequency from 2 to 12 kHz, there were positive (sometimes significantly positive) correlations with number correct in the LVP. In other words, poorer hearing at higher frequencies was associated with better lateral vertical localization performance, just as better hearing at lower frequencies was so associated. This was the case for the signal at 65 and at 50 dB SPL. The average better-ear HTL over 0.25 to 1 kHz yielded correlations with unaided LVP accuracy of -.62 at 65 dB SPL and -.74 at 50 dB SPL. The average better-ear HTL over 2 to 12 kHz correlated +.74 and +.62 with unaided LVP accuracy for the signals at 65 and 50 dB SPL, respectively.

The evidently contrary direction of these relationships prompted us to derive a “contrast” measure comprising the difference between lower and higher frequency HTL averages. The correlation between the contrast measure and LVP accuracy was .68 for the signal at 65 dB SPL and .88 at 50 dB—the greater the contrast, the greater the accuracy. These correlation levels are notably higher than the values for either frequency region alone, suggesting that the observed effect depends on the degree of disparity between hearing at low and high frequencies. Scatterplots of the relation between unaided LVP accuracy and the contrast between low- and high-frequency HTL are shown in Figure 5.

DISCUSSION

The purpose of this experiment was to examine the effect of earmold variation on localization ability in people with high-frequency hearing losses whose unaided performance on such a task was better than when using their own hearing aids. Initial unaided localization ability of those selected for the main experiment was the same as that of people who performed as well or better aided. This indicates that the negative effect on localization was due to the hearing aids and was not a reflection of generally poorer localization ability. Aided localization in the selected group was restored to unaided levels using open earmolds, confirming the fact.
that it was their own hearing aids/earmolds that had affected initial performance.

The most likely information for localization made available by open earmolds in the FHP is undistorted low-frequency time/phase differences. Providing small (1–2 mm) vents in a closed earmold does not appear to furnish this information—all but one of the selected group had vents in their own earmolds, yet aided performance with vents temporarily closed was no different from performance with the vents left open. By the same token, the extra-open (sleeve) earmold appeared to offer only limited further benefit for localization over the open mold. The sleeve earmold does allow better aided localization in people with good high-frequency hearing (Byrne et al., in press), but may not offer an advantage where poor high-frequency hearing means that the listener does not detect or rely on pinna cues, a point we return to later.

Poorer aided than unaided localization using a closed earmold might be explained by the fact that, in standard aided conditions, low-frequency sound arrives at the eardrum via two parallel paths: (a) aid-transmitted sound and (b) leak-transmitted sound coming in through a vent or leaking past the earmold (Dillon, 1991). The aid-transmitted sound has associated phase delay (due to the electromechanical characteristics of the hearing aid) and combines with the leak-transmitted sound to produce a “combination phase delay,” additional to any phase delay due to the ITD/phase difference.

If, at a particular frequency region, the aid-transmitted sound and the leak-transmitted sound are at comparable levels at the eardrum, then the combination phase delay will be highly sensitive to the ratio of the level of the aid-transmitted sound to the level of the leak-transmitted sound (the “aid/leak ratio”). This often occurs in the 250- to 750-Hz region for a high-frequency hearing loss fitting (Dillon, 1991). In this situation, interear differences in the aid/leak ratio of just a few dB, feasibly varying for different spatial positions, will cause interear differences in the combination phase delay, resulting in spatially inconsistent interaural time difference (ITD) cues. In other frequency regions, where either the aid-transmitted or the leak-transmitted sound dominates in both ears, consistency in the pattern of ITDs will be preserved. Open earmolds may provide relief by allowing the equivalent of “leak-transmitted” sound to dominate over most of the frequency region important for ITD cues (below 1.5 kHz). The values in Figure 3 show that for the open and sleeve fittings, insertion gain due to the aid-transmitted sound is 0 dB or less below 1 kHz; thus, unaided sound dominates in both ears, providing undistorted ITD cues.

Of the people tested initially, half showed poorer aided localization. This indicates that a significant proportion of clinic clients could potentially benefit, in terms of localization, from the use of an open earmold. Opening up the earmold can introduce acoustic feedback, and, for some people, volume levels had to be slightly reduced to below those normally used to prevent this in the present experiment.

Localization accuracy, unaided, in the FHP was strongly associated with low-frequency hearing, reflecting the point that better low-frequency hearing enables detection of the time/phase cue shown by Wightman and Kistler (1992) to dominate FHP localization. Explaining links between hearing level at different frequencies and other aspects of localization performance requires mention of the following theoretical issue. One basis for the current experiment was that stationary cues are the most significant for localization, and head movement has an uncertain role, if any (Middlebrooks and Green, 1991). Our previous experiments with hearing-impaired listeners have suggested no noticeable role for head movement, and we have generally ignored it as a factor. Recent findings from a separate project, using low-pass noise and listeners with normal hearing (Perrett and Noble, in press a, b), have led us to revise this view about head movement. With 1- and 2-kHz low-pass sounds (hence no pinna cues), rotation of the head makes it possible to discriminate front from back positions, and even source elevation.

The basis of these discriminations is the varying patterns of transformation ITD/phase differences due to the listener’s own movement. For example, a head rotation to the left generates a decrease in interaural differences for a source to the left and in front of the interaural axis. The same rotation generates an increase in such differences for a source to the left and behind, a distinction that allows front/back discrimination. Furthermore, the rate of change of such interaural differences varies as a function of the degree of elevation of the sound. For a sound at the horizon, a horizontal head rotation generates maximum change in interaural differences. For a sound directly overhead, no change occurs when the head is rotated. At intermediate elevations, the same head rotation generates changes, the rate of which declines as elevation increases above the horizon. Such
dynamic localization cues were originally proposed by Wallach (1939, 1940), but were thought, until these recent findings, not to be effective.

Head movement in the present experiment was more useful than we have observed formerly in people with impaired hearing. There were fewer front/back errors than we have found before, and, in some cases, we observed better than expected vertical plane discrimination. We argue that when people are selected who have poor high-frequency hearing but good low-frequency hearing, as in the present experiment, some may perform like those with normal hearing when listening with free head movement to low-pass noise. The correlation between HTL and LVP performance bears out this argument. Better low-frequency hearing together with poorer high-frequency hearing correlated with vertical plane localization accuracy. Listeners more proficient in the vertical plane had the greatest contrasts between low-frequency (0.25–1 kHz) and high-frequency (2–12 kHz) hearing, suggesting that they attended more consistently to the only vertical plane cue (the dynamic “Wallach” cue) available to them. Listeners with less of a low-high-frequency contrast did poorly in vertical plane localization, suggesting that an audible but distorted pinna cue is unfavorable compared with an undistorted dynamic cue. The second sort of hearing threshold configuration has been more common in our previous studies with hearing-impaired listeners, explaining why LVP performance has typically been poor.

Relatedly, front-back errors were minimal, except in closed aided conditions with the 50 dB SPL signal. In that condition, the incidence of those errors was strongly positively correlated (.84) with low-frequency hearing level, suggesting an interaction among increasing hearing loss, decreased signal audibility, and possibly also distortions of the dynamic interaural cue generated by the hearing aids/earmolds. Again, this outcome may explain why we have formerly observed a greater incidence of front/back errors even when head movement is permitted—more of our hearing-impaired listeners than in the present study have had poorer low-frequency hearing.

CONCLUSION

Assuming that other amplification needs of clients with poor high-frequency hearing are not diminished, the use of open earmolds commends itself in terms of permitting improved sound localization. This benefit adds to the other advantages of open earmolds, in terms of speech intelligibility and quality of the wearer’s voice, that have been previously reported in the literature. Our own recent investigations suggest that open earmolds may be associated with better speech hearing in spatially separated noise. Such an outcome may be related to localization ability (Noble et al, in press). Whether or not there is a link between those auditory functions is certainly a matter of clinical interest; it is satisfactory enough, however, if ways are found to improve, or at least not further impair, aided localization as such.

Acknowledgment. This study was supported by Grant #951031 from the National Health & Medical Research Council, Australia.

REFERENCES


